CHAPTER 4

GROUNDING

4-1. Purpose of grounding

The primary purposes of grounding for circuits, cables, equipment, and systems are to prevent shock hazard, protection of circuits and equipment, and reduction of electromagnetic interference (EMI) due to electromagnetic (EM) field, common ground impedance, or other forms of interference coupling. The various grounding systems used (lightning, power, and/or signal) are integral parts of a facility or system whether they involve vehicles such as automobiles, ships, missiles, or aircraft; buildings; or building complexes. Like other facility components, grounding networks are exposed to the ambient EM environment. This environment includes many sources ranging from incident radio frequency (RF) signals to lightning, and from atmospheric noise to internally generated stray currents.

a. The objective and plan of the facility ground network design should consider all aspects to the degree required for the particular mission of the facility in its environment and in the context of cost-effectiveness. The use of the term facility ground network is intended to be in the collective sense; it includes the power fault protection network, lightning protection network, building or structure (or frame, hull, fuselage skin, etc.) ground, equipment ground, signal ground, instrument ground, data ground, etc. Attempts should be made to integrate the three features of lightning protection, electrical safety, and EMI control.

b. The integration of these features in the design may be difficult because they usually do not fall under the responsibility of the same individual, group, or perhaps company, and they may not even be considered in the same time frame. In the case of a building, lightning protection and power grounding are often decided by an architectural and engineering firm during the structural design phase, and EMI control aspects are left to the electronic equipment engineers for resolution long after the building is finished. When this happens, tradeoffs become difficult. However, the various grounding networks must interface and they all must operate in a common EM environment. To alleviate this situation in future facilities, equipment designers and EMI engineers must be allowed to participate early in the facility design process. For existing structures, those persons responsible for electronic equipment grounding should become thoroughly familiar with the power and lightning-protection ground networks through reviews of drawings, performance of current and voltage measurements, and physical inspections before deciding upon the final signal/equipment grounding networks.

4-2. National electrical code (NEC) requirements for grounding

Requirements for the safe installation of electric conductors and equipment within or on various facilities are contained in National Fire Protection Association (NFPA) 70-1999 and the NEC. The purpose of the NEC is “the practical safeguarding of persons and property from hazards arising from the use of electricity.” The NEC is the most widely used code having been adopted by the majority of the states, counties, municipalities, cities, etc. The federal government, through the Occupation Safety & Health Administration (OSHA) adopted the NEC in 1971. Since this code is universally adopted, it serves as a basis for computers and computer systems’ equipment complying with the minimum requirements found in the Code.

a. The NEC contains the intent for grounding. The requirements for grounding the process control computers and distributed control systems are contained in several sections of the NEC. These sections specifically address equipment (enclosures), above 50 volts, below 50 volts, and grounding electrode.

b. The grounding of the electrical system and connection of the electrical system neutral to earth must be connected at only one point to the equipment grounding conductor. Reasons for the electrical system to be grounded are stabilization of the voltage (that is, to keep it from floating above a set reference point), facilitation of clearing phase to enclosures/ground faults, and limitation of lightning and line surges. The NEC calls for bonding the electrical system to the enclosures of (1) conductors and wireways such as conduit, and (2) equipment.

c. Article 250, Part F, of the NEC addresses the requirements for equipment grounding.

(1) The word "enclosure" is defined in Article 100 as "The case or housing of apparatus, or the fence or walls surrounding an installation to prevent personnel from accidentally contacting energized parts, or to protect the equipment from physical damage." In Article 250, Part D, "Enclosure Grounding" could be confused with the word enclosure as being similar to a raceway, which may be rigid or flexible conduit, wireways, busways, etc. All equipment enclosures will, therefore, be referred to simply as "equipment" as is done in Part F of Article 250. Although computers and distributed control systems are not mentioned in name, Section 645-15 states that "All exposed noncurrent-carrying metal parts of an information technology system shall be grounded in accordance with Article 250 or shall be double insulated."

(2) If the equipment is fastened in place or connected by permanent fixed wiring methods, which is not the usual case, then the exposed noncurrent-carrying parts likely to become energized shall be grounded, if within 8 feet vertically or 5 feet horizontally of ground or grounded metal objects and subjected to contact by persons (refer to Section 250-110). It can be inferred from Section 110-26 that concrete, brick, or tile floors are considered as grounded. Since the walls are assumed to be grounded, the floor could also be assumed to be grounded since it touches/attaches to the wall. However, to assure adequate ground protection the floor must be bonded to a known ground. Most computer systems are connected by cord and plug. Although these systems are not mentioned by name, it is accepted practice that the noncurrent-carrying equipment parts be grounded.

d. NEC 250-20(b) addresses the grounding requirements of electrical systems above 50 volts to 1000 volts. The article addresses systems supplying premises wiring and premises wiring systems. It does not address the electrical supply system powering the computers and distributed control systems. The building electrical system can be a grounded, ungrounded, or high impedance (resistance) grounded system. The definition of premises wiring from Article 100-A of the NEC is: "That interior and exterior wiring, including power, lighting, control, and signal circuit wiring together with all of their associated hardware, fittings, and wiring devices, both permanently and temporarily installed, that extends from the service point of utility conductors, or source of power such as a battery, a solar photovoltaic system, or a generator, transformer or converter windings to the outlet(s). Such wiring does not include wiring internal to appliances, fixtures, motors, controllers, motor control centers, and similar equipment." It is, therefore, prudent to assume that this section does not apply then to anything other than premises and excludes equipment connected by cord and plug.

e. Grounding requirements for electrical systems below 50 volts are addressed in Article 250-20(a). Thus, if computers and distributed control systems were to use electrical systems less than 50 volts ac, and if the conditions covered below apply, the ac system must be grounded.

(1) If the transformer supply system exceeds 150 volts to ground

(2) If the transformer's primary system is ungrounded

(3) When installed as overhead conductors outside of buildings

f. Section 250-30 of the NEC addresses the grounding of separately derived systems. Large automated data processing (ADP) systems can have a separately derived system through a delta-wye grounded transformer. This article of the NEC shall apply when an ADP is powered by such a network.

(1) The grounding electrode shall be as near as practicable to and preferable in the same area as the grounding conductor connection to the system. The grounding electrode shall be: (1) the nearest available effectively grounded structural metal member of the structure; or (2) the nearest available effectively grounded metal water pipe; or (3) other electrodes.

(2) There is an exception dealing with transformers rated not more than 1000 VA. A 1000 VA transformer can use the frame, and, therefore, a grounding electrode is not necessary. This exception is stated in Section 250-30(a)(2).

g. The key to one of the problems with computers and distributed control systems is found in Part H, "Grounding Electrode System," Section 250-50. This part of the NEC states: "If available on the premises at each building or structure served, each item (a) through (d), metal underground water pipe, metal frame of the building, concrete-encased electrode, and ground ring shall be bonded together to form the grounding electrode system." This is normally interpreted as meaning that all metallic systems within the structure shall be bonded such that they have a common ground plane. Where none of these electrodes are available, "Made and Other Electrodes" may be used as specified in Section 250-52. These electrodes consist of metal underground gas piping system, other local metal underground systems or structures, and plate electrodes.

(1) Many control system instruction manuals show rods as the only method of connecting to earth for the electrical system and the computer system. This is probably a carryover from the residential wiring practice, where the items listed as "grounding electrode system" are not available and "made and other electrodes" (rods) must be used.

(2) Section 250-60, "Use of Air Terminals" states that "Air terminal conductors and . . . rods . . . used for grounding air terminals shall not be used in lieu of the made grounding electrodes required by Section 250-52 for grounding wiring systems and equipment."

(3) Section 250-52 of the NEC states that "Where more than one electrode is used, each electrode of one grounding system (including that used for air terminals), shall not be less than 6 feet (1.83m) from any other electrode of another grounding system." The isolation between electrical systems, which was sought through separate ground rods, was usually non-existent. The electrical systems were actually tied together through the "sphere of influence." The radius of the sphere of influence of a driven rod is equal to the rod's depth. If a 10-foot rod is driven into the earth, everything within a radius of 10 feet will be under the influence of the 10-foot deep

rod. The average resistance between a second rod driven within a sphere whose radius is 10 feet and which is centered at the top of the first rod will be negligible. They would be considered as being connected together, assuming average earth conditions.

h. The authority having jurisdiction of enforcement of the NEC will have the responsibility for making interpretations of the rules, for deciding upon the approval of equipment and materials, and for granting special permission contemplated in a number of the rules (Section 90-4). If the installation complies with and exceeds the NEC requirements, both stated and inferred, no problems should be encountered in receiving approval for the installation. This will be true if all the electrical systems, grounding systems, equipment enclosures, etc., are all connected and bonded together.

4-3. System configurations

Electrical systems can encompass one item or several. A system may represent a small self-contained electronic circuit totally within the confines of a case, cabinet, rack, or it may be an extended collection of equipment racks or consoles distributed over a wide geographical area. The grounding requirements and procedures will be markedly different for these different types of systems. One way of distinguishing between different types of systems is to examine the manner by which power is obtained and how the equipment elements are interconnected with each other and with other systems. Based on these two considerations, systems may be identified as isolated, clustered, distributed, multiple-distributed, or central with extensions.

a. An isolated system is one in which all functions are accomplished with one equipment enclosure. An isolated system should not be confused with a floating system, which has no external ground. Some isolated systems may be floating while others must be grounded.

(1) Only a single power source is associated with an isolated system. (Single power source means one battery pack, one branch circuit supply, etc.). In addition, only one ground connection (to structure, to earth, to hull, etc.) for the entire system is needed for personnel protection or lightning protection, or no facility ground connection at all is required. No conductors except the power cord and the appropriate ground exists because no interfaces (power or signal) with other equipment or devices, which are grounded, are present or needed. Common examples of isolated systems are hand-held calculators, desktop computers (off line), home-type radios, television receivers, etc.

(2) Grounding requirements for isolated systems are illustrated by figures 4-1 and 4-2. They typically include a third wire ground if powered with single-phase ac or a ground-cable run with the power conductors if multiphase ac is involved. Double insulated systems as defined in NEC Article 250-114 are not required to have a third ground wire. Battery driven systems usually do not require any grounding, but the system should be isolated. It is important that isolated systems are not located near lightning down conductors, or near other grounded metal objects, and in areas where very high RF voltages may appear on equipment cases. The internal signal grounding requirements of the isolated system are those determined by the designer as necessary for proper self operation.

b. A clustered system as shown in figure 4-3 is characterized as having multiple elements, equipment racks, or consoles located in a central area. Typical clustered systems include minicomputers, component stereo systems, medium scale data processors, and multi-element word processors.

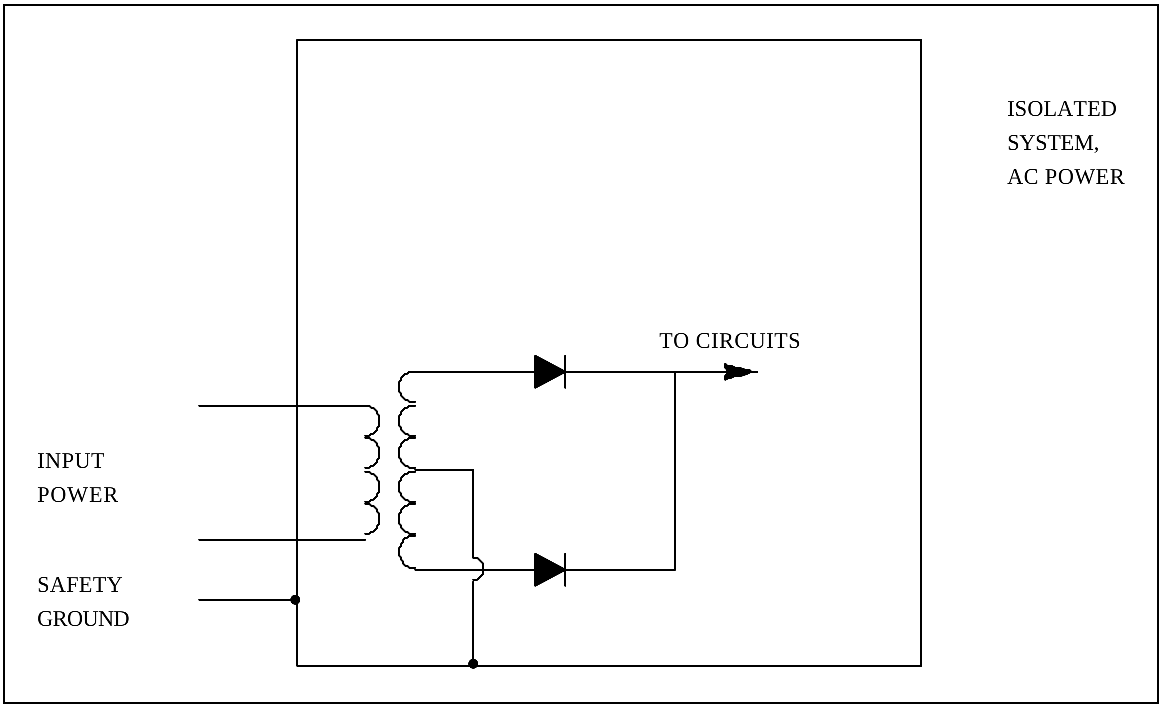

Figure 4-1. Minimum grounding requirements for ac powered isolated system

(1) A distinguishing feature of a clustered system is that it utilizes one common power source, e.g., a battery or a single ac power connection. There are likely to be multiple interconnecting cables (signal, control, and power) between the members of the system but not with any other system. A clustered system only needs one facility structure ground tie to realize personnel safety and lightning protection requirements.

(2) Grounding for a clustered system requires that one connection be made to structural ground as illustrated by figure 4-4. If the power supplied is single-phase ac, the third wire ground provides this connection. If the power supply is three-phase ac, (according to Paragraph 250-122 in the NEC) a supplemental ground conductor shall be installed. It shall be sized in accordance with Section 250-122 and Tables 250-66 and 250-122 of the NEC. Battery powered systems should have one ground connection to the structure. The signal ground referencing scheme used between the elements of the system should reflect the particular signal characteristics (frequency, amplitude, etc.) of the various pieces of equipment. This scheme may be single-phase or multiple-point.

(a) If a multiple-point scheme is used, the signal ground may be realized with cable shields, auxiliary conductors, or a wire grid or metal sheet under or above the array of equipment. In a benign (quiet) EM environment, signal grounding with cable shields or auxiliary conductors between the interconnected pieces is acceptable. In high level, multi-signal environments, this type of grounding scheme should be avoided because of the antenna pickup effects of the multiple conductors. Signals coupling to the ground conductors produce common-mode voltages between various source-load pairs and raise the threat of interference. A better method of

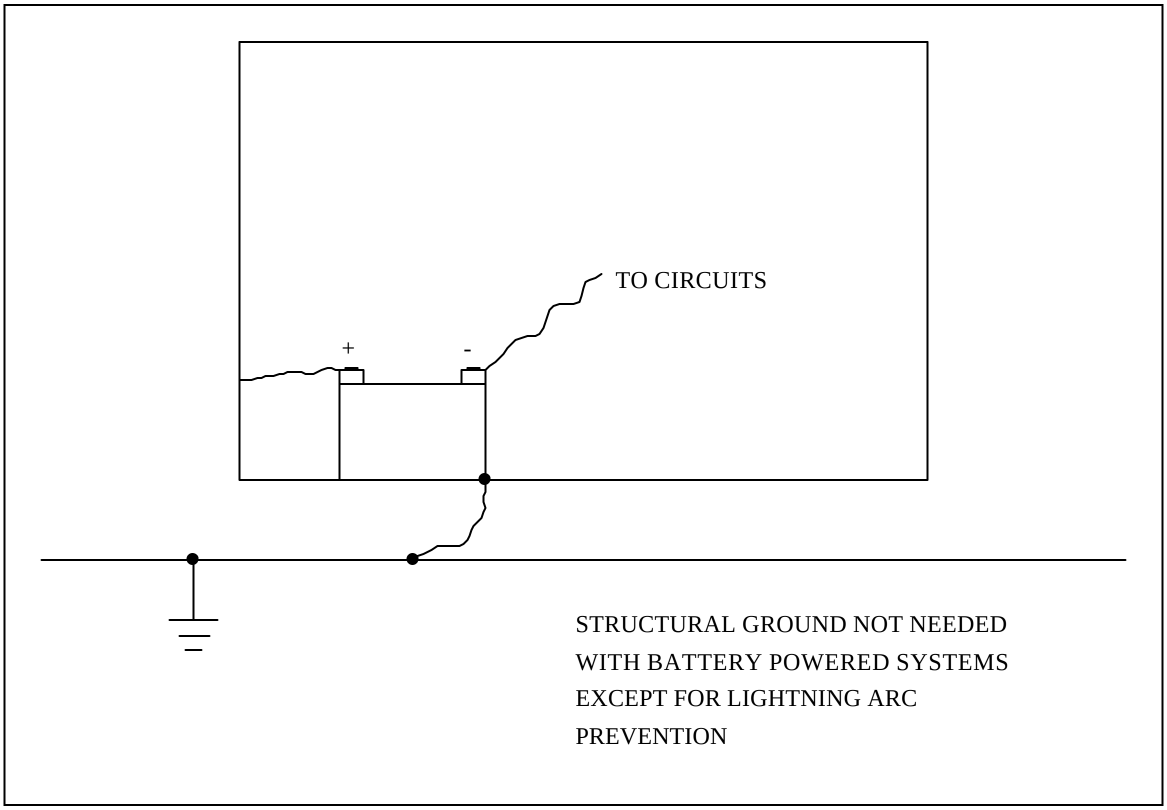

Figure 4-2. Minimum grounding requirements for battery powered isolated system

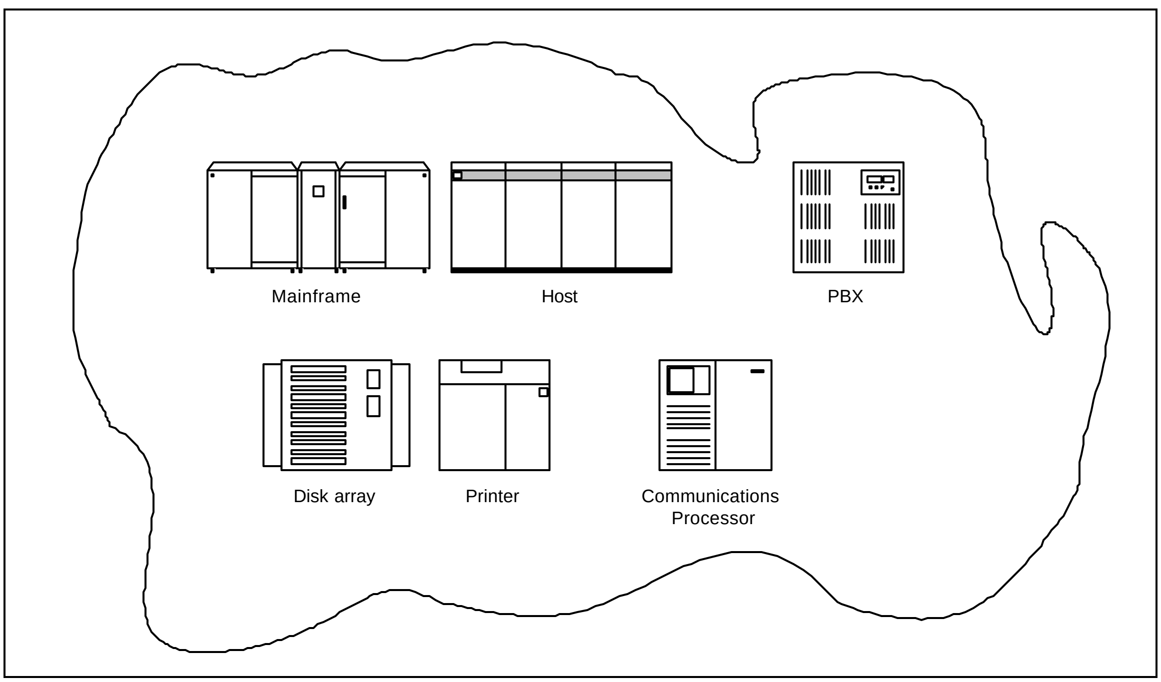

Figure 4-3. Clustered system

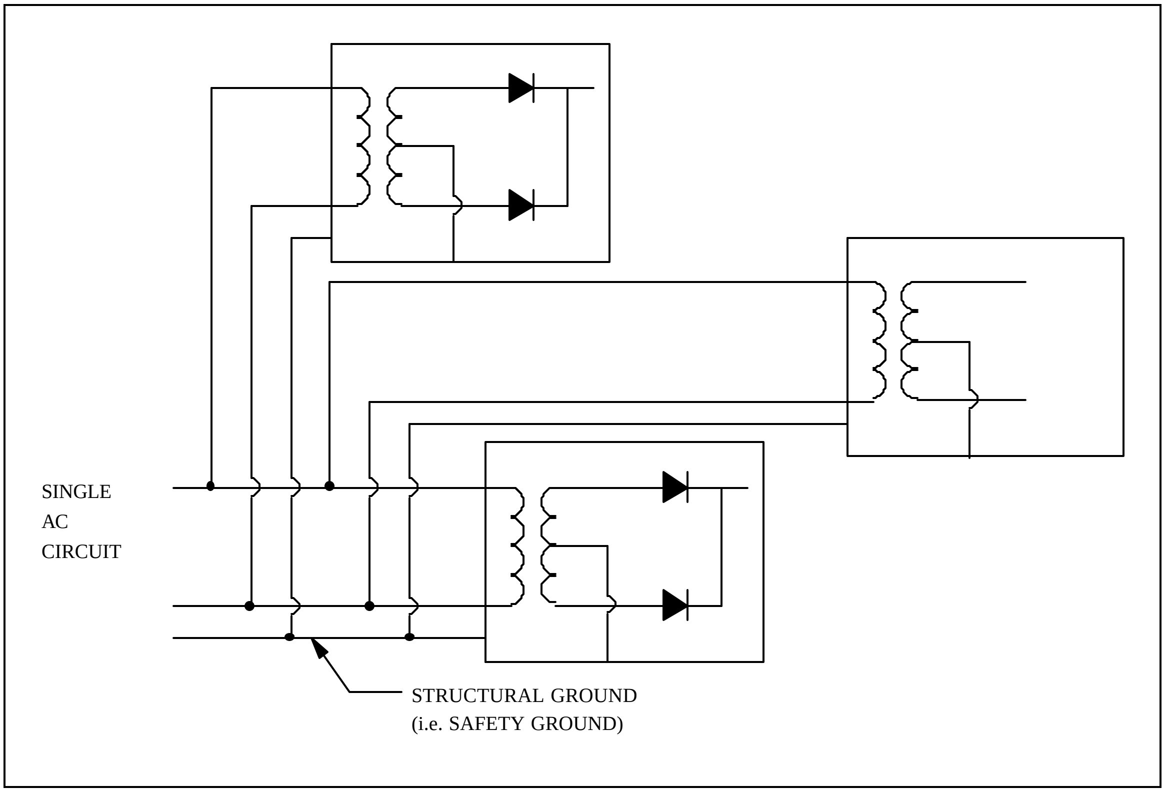

Figure 4-4. Basic grounding of a clustered system

grounding should provide broad metal paths between the pieces of equipment of the system. Overhead or underfloor ductwork, cable trays, and wire channels can frequently provide the necessary signal grounding and fault protection network for a clustered system. The best approach, and the one recommended for use in high level RF environments, will use a close-mesh wire grid or a solid metal sheet for mounting the various pieces of equipment of the system.

(b) In extremely severe environments as in the vicinity of a transmitter, the solid sheet is preferred over the grid. Each cabinet is carefully bonded to this grid or sheet. All interconnecting signal leads, power buses, etc., should be routed inside enclosures and beneath the ground plane, preferably in conduit or in raceways. Note that the evolution from the poorest to the best approach is aimed at rendering the system and its cables successively less effective as a pick-up antenna for radiated RF energy, particularly in the broadcast, high frequency, very high frequency, and ultra high frequency bands.

c. A distributed system is one in which major elements are physically separated in a way that requires equipment to be variously fed from different power outlets, branch circuits, different phases of the line, or perhaps even different transformer banks.

(1) In a distributed system, separate safety and lightning protection grounds to the facility (vehicle) structure (frame) are required. Another common characteristic of a distributed system is that multiple conductor lengths are likely to be greater than 1/10 of a wavelength at frequencies where an interference threat exists. Examples of distributed systems include industrial process control, environmental monitoring and control, communications switching, and large main frame computer nets.

(2) Effective grounding of distributed systems to achieve the required safety and lightning protection for equipment and personnel, while minimizing noise and EMI, requires careful application. To describe a stereotyped network or to list a set of rules is not considered prudent. General guidelines follow.

(a) If the system is ac powered, consider each major element (consisting of one or more types of equipment essentially located at a particular location) as either an isolated or clustered system, as appropriate. Proceed to ground each major element. Each and every signal port on these isolated or clustered subsystems that must interface with other portions of the total system, i.e., other subsystems, should be viewed as interfacing with a noisy world. As such, the techniques for controlling unwanted coupling of radiated and conducted interference into the signal paths must be fully employed. Obviously, discretion will be necessary. There will be situations, depending upon the properties of the signal being transmitted from terminal to terminal, the characteristics of the signal path, and the nature of the EM environment, in which no additional protective measures are required. In general, adequate isolation must be provided between the external (to the system) conducted and radiated noise environment and the signal path.

(b) Common battery distributed systems present a particular challenge. Such systems are commonly found on aircraft where the fuselage is used for dc power return. The use of the equipment rack, structure, hull, or fuselage for the power return path means that the structure becomes the circuit reference. Therefore, voltage differentials between various points in the structure appear in series with any single ended, unbalanced signal paths. Again, adequate rejection against such conducted interference must be obtained.

(3) Multiple distributed systems are similar to that of a distributed system except that there are usually several systems contained and operating in the same general area. Typically, the multiple systems share the primary power sources. A distinguishing feature of multiple distributed systems is that they typically run a high risk of interfering with each other and are susceptible to interference from facility noise and the external environment. Thus, in addition to having grounding requirements like those discussed for distributed systems, additional shielding and filtering requirements are necessary to minimize intersystem interference.

d. A central system with extensions is illustrated in figure 4-5. It is distinguished from an isolated or clustered system in that integral elements of the systems extend out from the central portion at long physical and electrical distances. This system is distinguished from a distributed system in that the extended elements obtain their power from the central element. Connections to a power source are not made anywhere except at the main element. An example of this type of system is an industrial process controller with sensors and actuators located remotely from the data logger or controller.

(1) The central or primary element of this type of system should be founded as though it were a clustered or isolated system. Depending upon the operating frequency ranges and signal levels of the extension elements and the characteristics of the EM environment, a single-point tree or star grounding scheme may be used or a multiple-point scheme may be used.

(2) It is likely that most systems of the central-with-extensions configuration will involve relatively low frequency (audio or below) with operating bandwidths encompassing the power frequencies. If this is the situation, a single-point tree is recommended. The ground mode would be at the central element with one connection (the safety ground) made to the structure. Extended elements should be floated or balanced. Twisted pair or balanced signal transmission-line

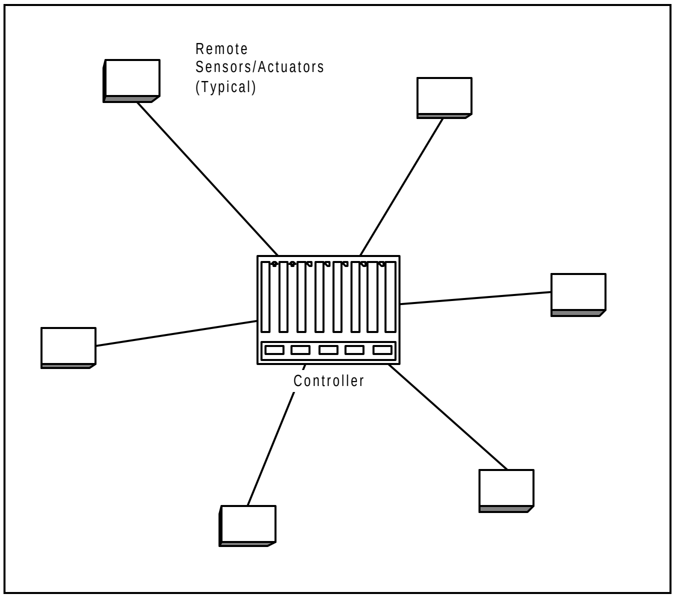

Figure 4-5. Central-with-extensions system

conductors should be used between the central element and the extended elements. If radiated coupling proves to be a problem, the extended elements should be configured, if at all possible, so that the shields (as on coax, for example) from the central element can be continued to enclosure the extended elements.

4-4. Ground configurations

a. Single-point grounding means connecting one point (either the source or load end) of the signal return side of the energy transfer loop to ground. There are many applications, which require single-point grounding. Although definitely advantageous in many situations, in a multi-equipment system or facility a single-point ground system can be very difficult to implement and maintain as a true single-point ground system.

b. Multiple-point ground attempts to realize an adequately low ground plane impedance, i.e., minimize ground reference voltage differentials, is the basis of multiple-point grounding. In multiple-point grounding, the source and load end of every energy (signal) transfer pair is connected to a ground plane (chassis, equipment cabinet, structural frame, printed circuit board, etc.) by the shortest electrical path. The ground plane is also interconnected by the largest feasible number of parallel paths. Ideally, the ground plane would consist of a solid metal mass of lowest possible resistance.

c. A signal ground is necessary for RF equipment and circuits which frequently utilize the chassis, cabinet, or large unetched areas on printed circuit boards as ground planes for the signals of primary interest. Large, common areas are effective RF signal grounds because wide metal paths exhibit lower inductance, and thus lower impedance, than do round wires or narrow rods. To retain the ground plane effectiveness, paths serving as individual component, device, or network grounds must be short to minimize the circuit-relative impedance; thus, the overall ground must be brought to the component, device, or network. RF interfaces (input and output signal ports) are typically unbalanced and thus cable references, or signal grounds, must be the same as the chassis or cabinet ground.

d. The control of ground plane impedance is important in ensuring a noise-free system. Interference between circuits and systems always exists between ground conductors.

(1) Grounding conductors and paths exhibit inductive, capacitive, and resistive properties. Having such properties means that grounding conductors and paths rarely provide the zero impedance, or equipotential, reference plane which is sought for the grounding of signals. Any unwanted signals, whether they are power or microwaves, pose a threat of interference to desired signals whose circuits are referenced to the network.

(2) If both source and load ends of a circuit are connected to a noisy ground reference, a possibility exists for interference. Obviously, if the voltage differential between the source and the load is reduced, the interference threat is reduced.

(3) Reduction of interference can be done through lowering the impedance of the path through which the interference currents (and, frequently, the desired signal currents) are flowing.

(4) Ground noise problems can frequently be solved by providing more ground paths through the bonding of all metallic members of an equipment cabinet, or of a structure, together with low impedance interconnections. The technique, if thoroughly applied throughout a facility, can be very effective in reducing ground system (plane) impedance. The use of massive ground-return conductors, grounding sheets, or large area plates are frequently helpful.

e. In situations where single-point grounding is required at RF frequencies, capacitive grounding can be used. This is referred to as frequency-selective grounding. The inverse situation can also be employed where an inductance is used to achieve a dc and low frequency ground (e.g., for safety) and approximate an open circuit at RF. Parasitic effects can render capacitive and inductive grounding highly unpredictable and should be used only under unusual conditions and with a great deal of care to assure that the overall interference problem is not aggravated.

4-5. Grounding for fault protection

Fault protection is an integral part of ground network design. Frequently, signal grounds are common with fault protection paths, particularly where structural elements of a building are involved. Because traditional practices and personnel and structural protection requirements strongly favor that priority be placed on fault protection needs over EMI needs, it is likely that signal ground networks must be designed to be compatible with these networks. Occasionally, requirements of fault protection will force compromises in the signal ground design and implementation. The following discussion presents an overview of the principles of design behind fault protection systems.

a. One primary reason for grounding is to prevent electric shock in the event of a circuit fault. Electric shock occurs when the human body becomes a part of an electric circuit. It most commonly occurs when people come in contact with energized devices or circuits while touching a grounded object or while standing on a damp floor. The effects of an electric current on the body are principally determined by the magnitude of current and duration of the shock. Current is determined by the open circuit voltage of the source and total path resistance including internal source resistance and human body resistance.

(1) In power circuits, internal source resistance is usually negligible in comparison with that of the body. In such cases, the voltage level, V, is the important factor in determining if a

shock hazard exists. At commercial frequencies of 50 to 60 hertz and voltages of 120 to 140 volts, the contact resistance of the body primarily determines the current through the body. This resistance may decrease by as much as a factor of 100 between a completely dry condition and a wet condition. For estimation purposes, the resistance of the skin is usually somewhere between 500 and 1500 ohms.

(2) An electric current through the body can produce varying effects including death, depending upon the magnitude of current. For example, the perception current is the smallest current that might cause an unexpected involuntary reaction and produce an accident as a secondary effect. Shock currents greater than the reaction current produce an increasingly severe muscular reaction. Above a certain level, the shock victim becomes unable to release the conductor. The maximum current at which a person can still release the conductor by using the muscles directly stimulated by that current is called the let-go current. Shock currents above the let-go level can begin to cause check muscles to contract and breathing to stop. If the current is interrupted quickly enough breathing will resume. At a still higher level, electric shock currents can cause an effect on the heart called ventricular fibrillation. Under this condition, usually there is a stoppage of heart action. Various current levels for 60 hertz and dc are summarized in table 4-1. At frequencies above 300 hertz, the current levels required to produce the above effects begin to increase due to skin effort. For example, the perception current is approximately 100 milliamperes at 70 kilohertz (kHz). Above 100-200 kHz, the sensation of shock changes from tingling to heat. It is believed that heat or burns are the only effects of shock above these frequencies.

b. To protect people from inadvertent exposure to hazardous voltages, all exposed metallic elements should be connected to ground. In this sense ground usually means other exposed equipment, metal members of the building, plumbing fixtures, and any other metallic structures likely to be at a different (hazardous) potential in the event of a fault.

(1) If accidental contact occurs between energized conductors and chassis, frame, or cabinet through human error, insulation failure or component failure, a direct low resistance path

Table 4-1. Summary of the effects of shock

Alternating Current (60 Hertz) (milliamperes)	Direct Current (milliamperes)	Effects (milliamperes)
0.5-1	0-4	Perception
1-3	4-15	Surprise (reactor current)
3-21	15-80	Reflex action (let-go current)
21-40	80-160	Muscular inhibition
40-100	160-300	Respiratory block
Over 100	Over 300	Usually fatal

exists between the fault and the energy source (usually a transformer) which causes fuses to blow or breakers to trip and thus quickly remove the hazard.

(2) The dependence of shock effects upon frequency suggests that the relative danger from electric shock is related to the duration of exposure so that one objective of the fault protection system (network) is to reduce the time of exposure to a minimum. Another reason for achieving rapid clearance is to limit temperature rise in the faulted conductor and thus minimize a potential fire hazard.

c. Fault protection design is normally governed by the NEC and other established industry standards. The NEC is issued by the NFPA as NFPA 70 and is updated every three years. This code has been adopted by the American National Standards Institute (ANSI) as ANSI/NFPA 70 and it is rapidly becoming universally accepted. It has become, in effect, a Federal Standard with its incorporation into the OSHA requirements.

(1) When viewed from the perspective of EMI and noise control, it should be remembered that the primary objectives of the NEC are fire and shock hazard protection and not the achievement of EM compatibility. However, this does not mean that practices of the NEC are necessarily in opposition to good EMI practices. It does mean that the NEC standards must be met in any equipment or system design and installation and, therefore, its requirements must be thoroughly understood while implementing any EMI grounding system. Another thing to realize is that simply conforming to the NEC does not assure a noise-free system; generally other measures also must be employed to achieve the desired level of total system (equipment, facility, and environment) compatibility.

(2) Article 250 of the NEC sets forth the general grounding requirements for electrical wiring in a structure. Present requirements of the NEC specify that the ground lead (green wire), in a single-phase ac power distribution system, must be one of three leads. The other two leads comprise the hot lead (black wire) and the neutral lead (white wire). The ground lead is a safety conductor designed to carry current only in the event of a fault. The hot lead is connected to the high side of the secondary of the distribution transformer. For fault protection, the NEC specifies that the neutral be grounded at the service disconnecting means (main breaker). The safety ground (green wire) is grounded at that point as shown in figure 4-6. All exposed metallic elements of electrical and electronic equipment are connected to this ground with the green wire.

(3) Grounding of a three-phase wye power distribution system is done similarly to the single-phase system. The connections for a typical system are shown in figure 4-7. The neutral lead, as in single-phase systems, is grounded for fault protection at the service disconnecting means. The NEC specifies that the neutral should never be grounded at any point on the load side of the service entrance on either single-phase or three-phase systems.

(4) Figure 4-8 illustrates two correctly wired branch circuits. In the separate branch circuit, two pieces of equipment are energized from separate branch circuits. Minimum power-related voltages exist between the equipment cabinets A and B. Thus, potential interference currents in the interconnecting ground path (provided, for example, by a ground bus, cable shield, etc.) are small. The common branch circuit in figure 4-8 shows both pieces of equipment sharing a common-branch circuit, as in the same room, for example.

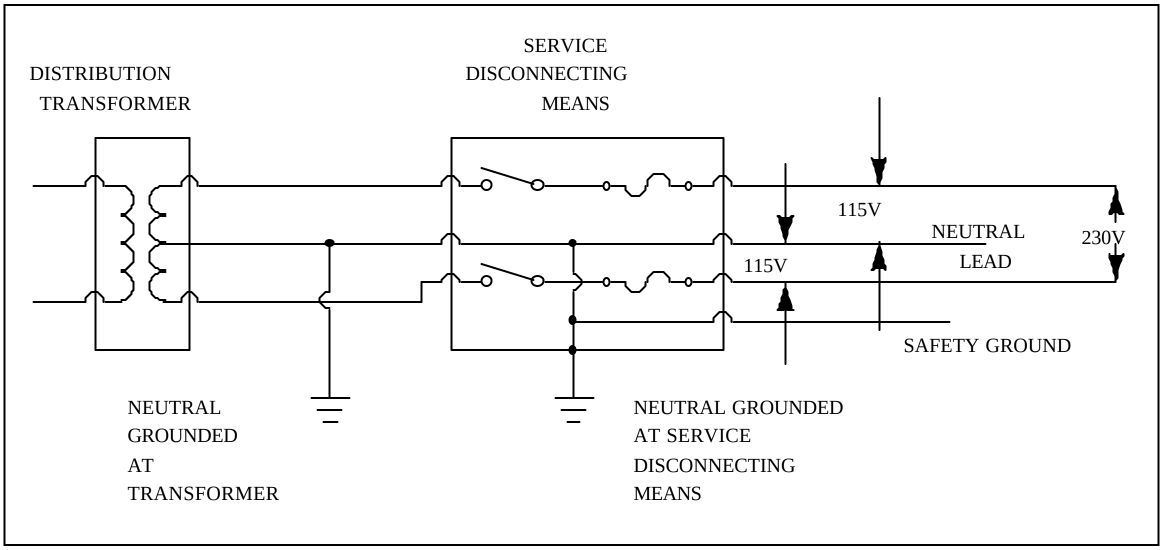

Figure 4-6. Single phase 115/230 Vac power ground connections

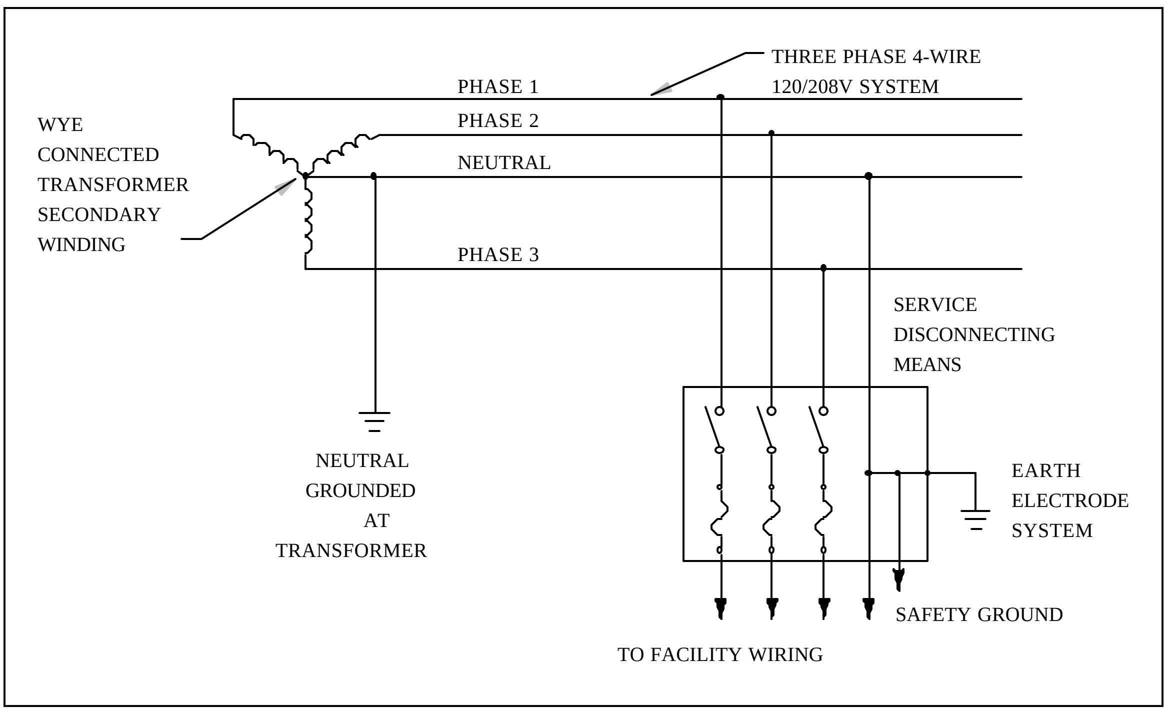

Figure 4-7. Three phase 120/208 Vac power system ground connections

(5) Figure 4-9 shows the effects of improper wiring.

(a) The hot neutral reversed condition is that of reversal of the hot (black) and neutral (white) conductors. Although a violation of the NEC, it does not automatically produce stray or return currents in the safety wire (or equipment cabinet/conduit system).

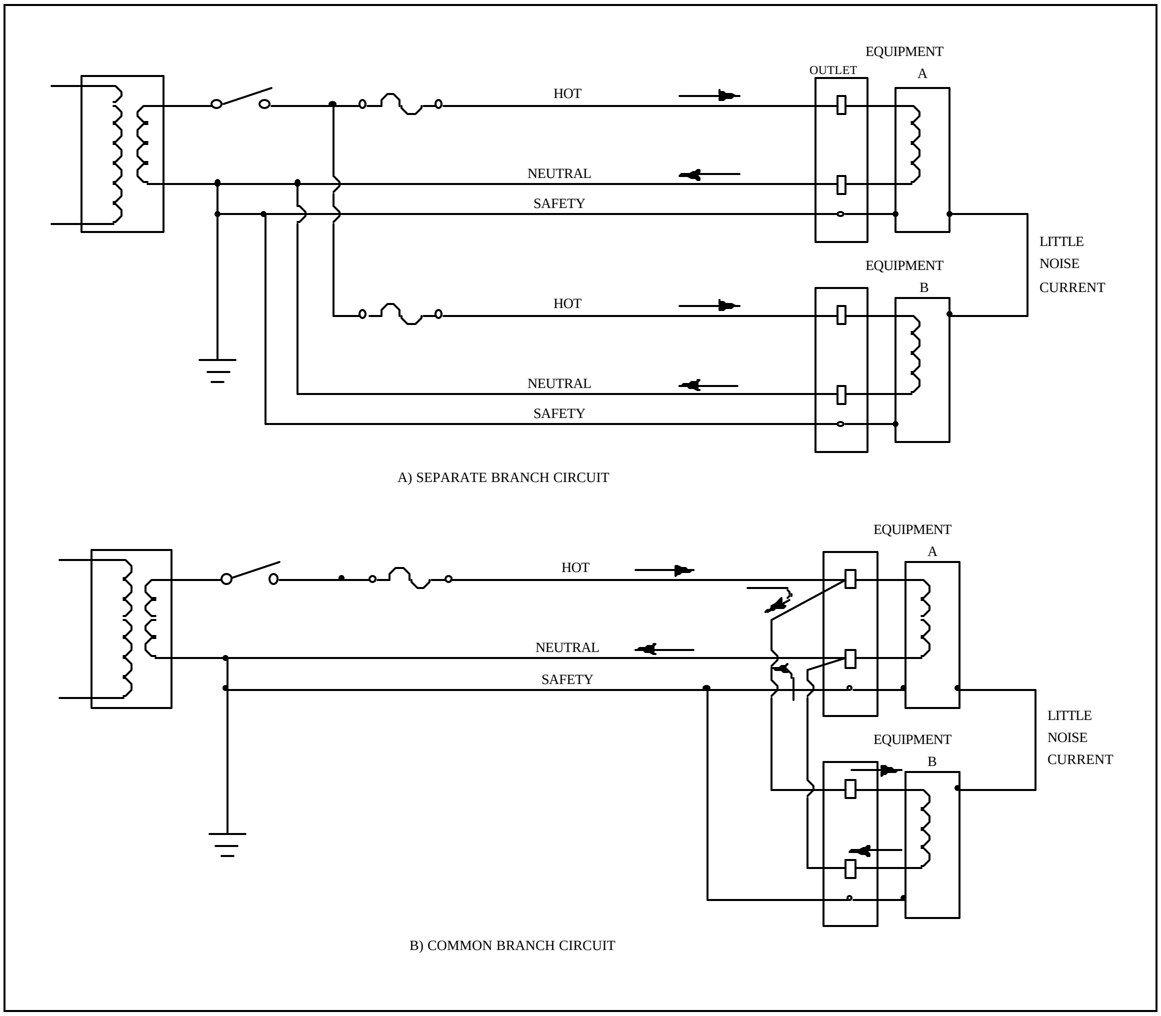

Figure 4-8. Properly wired ac distribution circuits for minimum ground noise

(b) The other conditions of figure 4-9 represent the most likely problems and are the most troublesome from the standpoint of stray noise. Interchange of the neutral and ground conductors frequently exists because no short circuit is produced and the condition may go undetected. The full load current of terminating equipment, however, returns through the safety wire/conduit/cabinet ground system. The resultant common-mode voltages and currents pose a severe threat to interconnecting circuits between equipment A and B. The condition of neutral safety interchanged, separate branch circuit is the most troublesome from the standpoint of power frequency common-mode noise because of the higher voltage drop developed by the return current traveling through the longer path.

(c) These conditions are the sources of many facility ground noise problems. Improperly grounded neutrals can occur in a piece of terminating equipment or can be the result of improper wiring at an outlet, junction box, or switch panel. (The most common cause is improper wiring.) If the neutral is grounded at any point except at the service disconnect, part (if not most) of the load current returns from the load back through conduit, raceways, equipment cables (including coax and other cable shields), and structural support members. Voltage drops associated with this return load current appear as common-mode noise sources between

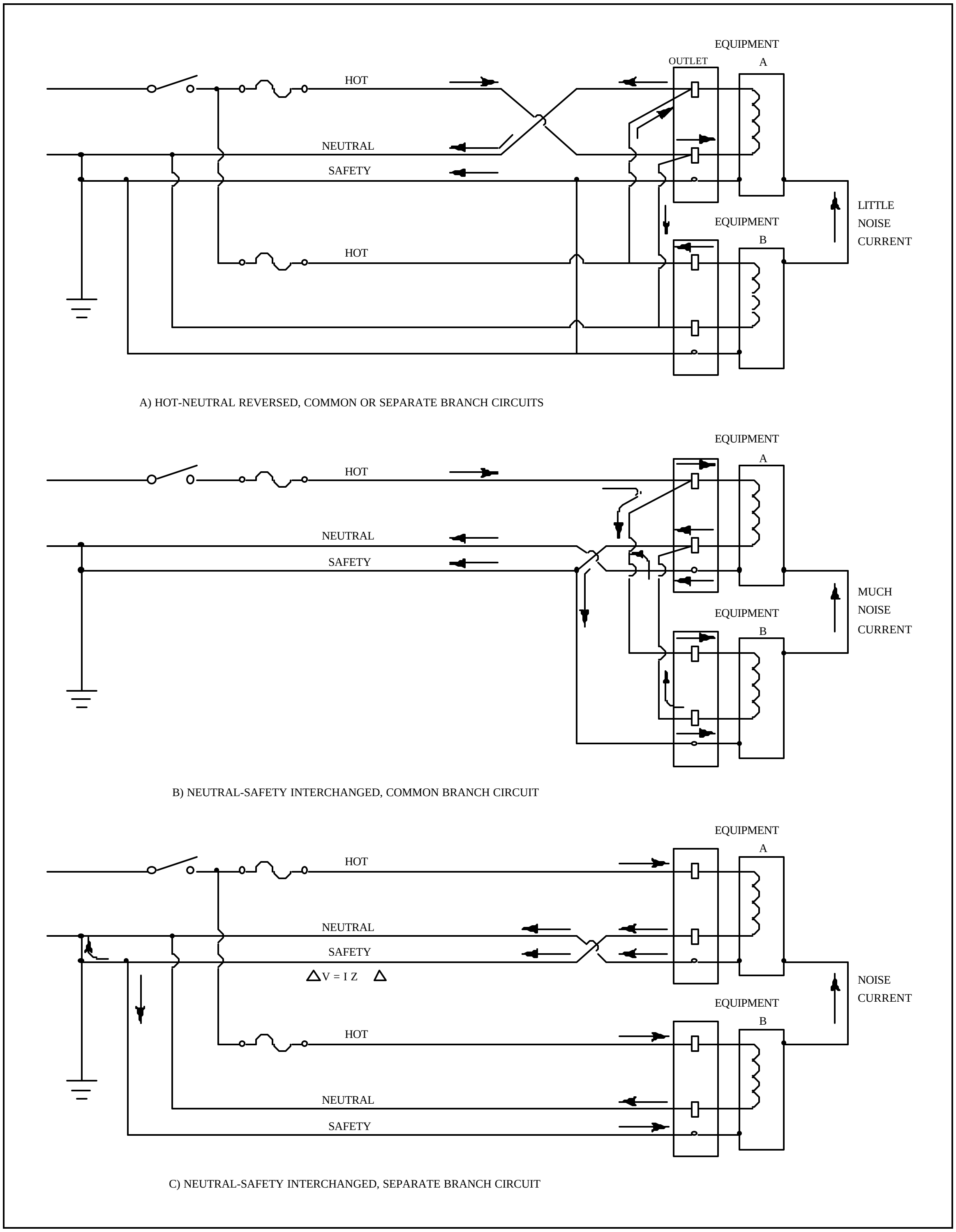

Figure 4-9. Noise problems resulting from improper wiring

separately located equipment, as illustrated. If this equipment must be interconnected with signal paths, appropriate common-mode rejection measures must be employed in the signal paths.

4-6. ADP grounding

The primary objective of grounding for computers and data processing equipment is to minimize electronic noise that would adversely affect the output signals of the equipment. The power-distribution system for computer rooms is usually designed by an electrical consultant and installed by an electrical contractor to insure maximum reliability. Grounding provisions provide personnel safety equal to or exceeding the requirements of the NEC. The computers and data-processing equipment are usually designed and installed by computer manufacturing companies or their contractors, in cooperation with the user-purchaser. The computer-room installation often includes a raised floor, with power to computers, peripheral equipment, interconnections, computer cooling-air distribution, and a fire-extinguishing system all located under the floor. This is where the usual interfaces are accomplished and where problems frequently occur between the computer installation and the electrical distribution system powering the computers. Grounding methods have been developed to minimize noise, sometimes isolating the computer equipment grounding system from the rest of the building grounding system. However, some of these methods are violations of the NEC grounding requirements and may be unsafe.

a. To prevent electrical noise from affecting computers, two entirely different and separate grounding systems are required.

(1) First, the power distribution system must be grounded in accordance with NEC requirements for safety, and in addition the 60 hertz power system grounding must be so designed that it will minimize noise pickup that can affect the computer operation.

(2) Second, the computer equipment and enclosures must be connected to a reference grounding system for high-frequency noise. This high-frequency protection is in no way related to system grounding. In fact, the high-frequency reference will work whether or not it is grounded to the system ground. However, since it consists of exposed, metallic noncurrent-carrying parts that could accidentally become energized, it must be grounded, as required by NEC Section 250-42.

(3) Once it is recognized that proper computer grounding requires both a 60 hertz and a high-frequency grounding system, that electrical safety requires that the two systems be bonded together, and that each system can be examined separately, then it can be determined how to bond them so they are compatible.

b. The grounding of computer equipment is done in accordance with NEC Article 645, Information Technology Equipment (ITE).

(1) Computer equipment grounding, like all other electrical equipment grounding, has only one purpose -–safety. The grounding performs two functions. First, it ties all equipment together with low-impedance conductors so all equipment is at the same potential. It also bonds that system to the grounding-electrode system so that the potential is that of the earth. If the grounding is done in accordance with the NEC, there should not be an unsafe difference in potential between any two pieces of exposed noncurrent-carrying metal or from any noncurrent-carrying metal to ground, even under fault conditions. Second, the equipment grounding provides a safe, low-impedance return path for ground-fault currents to permit overcurrent devices to clear the fault quickly and thus minimize damage.

(2) Where the power system supplying the computer has a grounded conductor (which is usually the case, since most computers utilize a 208Y/120V power supply with a grounded neutral), that conductor must be grounded in accordance with Article 250. This is frequently a source of confusion and conflict when the computer is supplied from a separately derived source such as a dedicated transformer or an uninterruptible power supply (UPS) or motor-generator (M-G) set. The NEC requirements are intended to ensure a safe installation and are not concerned with whether or not the system works properly so long as it is safe. It is important to keep this in mind. It is necessary to conform to the code and at the same time design and install a computer grounding system that will permit the computers to operate with a minimum of noise problems and data-handling errors.

(3) In a mistaken effort to isolate the computer system from the rest of the building power system, many systems have been grounded to a ground rod or buried ring around the building but not connected to the building grounding system and grounding electrode. This isolation has often been achieved by using many makeshift devices to keep the computer equipment insulated from the metallic parts of the distribution system.

(4) Power-supply conduits have been insulated from computer cabinets with polyvinyl chloride (PVC) conduit fittings or even plumbing fittings. Conduit runs have been ended before reaching the computer cabinet and the conductors run the remaining distance exposed. Green-insulated grounding conductors have been run separately from the circuit conductors and to a separate ground point. Ground pins have been cut off plugs and the green wire left floating. Flexible cords, without grounds, have been used to supply the computer units, and so on.

(5) All these schemes are unsafe, because there is no low-impedance return path for fault current and no assurance of equal potential between the equipment and other grounded metal. They violate many sections and every intent of the NEC. Finally, they often result in more computer noise than proper grounding would produce, because the multiple ground points can have differences in potential between them, causing circulating ground currents and false data inputs or processing.

(6) Computer grounding must be done in accordance with NEC Article 250 and consist of computer-equipment grounding and computer power-system grounding. All equipment grounding essentially requires that exposed noncurrent-carrying metal parts be connected by equipment grounding conductors to the grounding electrode at the electric service equipment, or at the power source if power is obtained from a separately derived system. The equipment grounding conductors must run with or enclose the circuit conductors and may be one or more of a combination of the types listed in NEC Section 250-91. These include a bare or insulated conductor, rigid or intermediate metal conduit or electrical metallic tubing, flexible metal conduit approved for the purpose; the armor of Type AC armored cable; cable trays; and other raceways specifically approved for grounding. An insulated grounding conductor must have an outer finish that is green or green with a yellow stripe. The grounding path must be permanent and continuous, and conductors must be sized and installed in full compliance with the many other applicable code requirements.

(7) Computer equipment grounding will comply with the code and will be safe if it meets these requirements. However, several additional provisions are necessary if the computer installation is to operate with minimum noise problems from the ground system. If computer equipment is installed in the same way as most other electrical equipment, the grounding may create many multiple grounding paths. The grounding conductors are run with the power conductors from the source to each piece of equipment, but there are also many pieces of

equipment fed from other equipment, and many other metallic interconnections between the grounded metal enclosures of various units. This can be perfectly safe, and in accordance with the code for equipment grounding, but the multiple points of grounding can have slight differences in potential, causing small ground currents to flow, especially under transient conditions. These ground currents appear as noise to the data-processing equipment and can cause errors in computation or component failures. This arrangement produces "ground loops" – multiple paths for the circulation of ground currents.

(8) By modifying the grounding these ground loops can be eliminated. Each piece of equipment is fed separately and radially from the source and is grounded (by means of the metallic raceway, green-wire ground, and any other grounding conductors) to a single computer ground point (G) at the source or distribution point. This radial grounding eliminates any ground loops. In addition, each piece of equipment is connected by the shortest possible connection to the reference grid. While these connections seem to create multiple ground loops, as explained earlier, all points on this reference grid are at the same potential, not only at the power frequency of 60 hertz, but also at much higher frequencies, so no currents will circulate. One point on the reference grid must also be tied to the computer ground point to put it at the same ground potential as all other equipment.

(9) A radial installation made as shown to a single ground point can comply in all ways with the NEC, can be entirely safe, and at the same time can be as free as possible from computer noise problems originating from the grounding system.

(10) Another point of confusion in computer grounding is the selection of the proper grounding electrode to which the computer grounding system must be connected. A frequent error of computer manufacturers is to request a grounding electrode separate from and not connected to the power system electrode – a separate ground rod or ground ring. This is not only unsafe and a code violation; because of differing ground potentials, it can also be a source of, rather than a cure for, computer noise problems.

(a) The proper grounding electrode is clearly spelled out in Article 250 of the code. Where the building service is the source of supply, the grounding electrode must be one or more of those types listed in Section 250-81, to which the grounded circuit conductor (neutral) must also be connected. There is little confusion on this point. However, large computer installations are frequently supplied from a separately derived system rather than direct from the building service. This is done to isolate the computer supply from the other building power systems, and often to condition the computer power to make it more reliable and compatible with computer requirements.

(b) The separately derived system may be a transformer, a computer power center, a M-G set, a synthesizer, or a UPS inverter. In all such cases, the required grounding electrode must be as near as possible to the source of power, the separately derived system (Section 250-26). The grounded conductor, or neutral, of the separately derived system and all equipment grounding conductors must be connected to this grounding electrode, not the one at the building service. A connection may also be made back to the service grounding electrode through the metallic raceway system; but this is neither required by code nor necessary for safety. The reason for this is that any fault currents that flow in the separately derived system must have a low-impedance path back to their source - the separate system source, not the building service.

(c) For separately derived systems, the preferred grounding electrode is the nearest effectively grounded metal structural building steel, or the nearest effectively grounded metal

water pipe. If neither of these is available, other electrodes as listed in Section 250-81 or 250-83 may be used. We have seen installations with grounding connections run several hundred feet back to the service ground from a computer transformer secondary, when the connection could have been and should have been made to the steel building column only a few feet away.

(d) Ground the computer equipment radially to a single ground point, tie it to a high-frequency reference grid, and ground this grid to the same computer ground point. Ground the computer ground point to the proper grounding electrode, and a computer grounding system that is electrically safe and meets all code requirements, will be essentially free of ground-caused computer noise and problems.

c. Computers input, process, and output data at tremendous rates which are constantly increasing. Typical computer clocks that control the data transfer into, within, and out of the computer operate at very high frequencies [upwards of 1 gigahertz (GHz)]. These are radio frequencies, and computers are sensitive to these frequencies. The wiring can act as a receiving antenna and can respond to external RF signals that may cause false data to be processed by the computer. The RF signals that can radiate from or get into computers are known as EMI.

(1) Computer microprocessors operate at very low voltages – usually 5 to 12 volts. Therefore, it is critical that unintentional voltage differences between various units of data-processing equipment in a computer room be extremely small. At 60 hertz this is relatively simple – just tie them together with a low resistance, low-impedance grounding conductor so the enclosures and grounded metal are all at the same (ground) reference potential.

(2) At radio frequencies the solution is not so simple. Low-impedance grounds are not easy to obtain, since the inductive reactance of a conductor is proportional to the frequency. At 30 megahertz (MHz), a length of conductor has an inductive reactance 500,000 times the reactance at 60 hertz. In addition, there is stray inductance and capacitance from conductor to conductor or conductor to grounded metal and resonance effects at high frequencies, making it very difficult to get a conductor of any appreciable length to have the same voltage at both its ends. If there is a difference in potential between the ends of a grounding conductor connecting two pieces of data processing equipment, it is possible for data errors to occur.

(3) A high-frequency impulse applied to a conductor travels along the conductor at a finite speed, about 85 percent of the speed of light, until it reaches the end of the conductor. It is reflected back along the conductor, becoming a traveling wave. At some frequencies, the reflected waves meet and reinforce oncoming new waves, creating resonances and standing waves. At or near these resonant frequencies the conductor appears to have an extremely high impedance and does not provide an effective voltage equalizing means between two pieces of equipment. In addition, the conductor can act as an antenna at or near these resonant frequencies, radiating energy that can interfere with other equipment or receiving stray signals from other sources and presenting a false voltage signal to the computer equipment.

(4) These effects are completely unpredictable because the interfering signals are not steady and because data processing equipment sensitivity varies. Digital computers on binary signals, on or off, or 0 to 1. The circuits are most sensitive at the moment they are switching from one state to the other, and if an impulse occurs at that moment, a false “bit” of data may occur in the system. At other times, the same impulse may not affect the processing. These errors can be extremely difficult to identify.

(5) This points out the need to interconnect all cabinets of the system in such a way that they are at the same potential for all frequencies, from 60 hertz or less to very high radio frequencies. One of the best ways of accomplishing this is the signal reference grid. Transmission-line testing has shown that standing waves will not cause a significant voltage difference between the two ends of a conductor that is not longer than about 1/10 to 1/20 of a wavelength. The wavelength at 10 MHz is about 100 feet and 1/20 wavelength is 5 feet. The wavelength at 30 MHz is about 32 feet and 1/20 wavelength is a little under 2 feet.

$$\lambda = c/f$$

where λ = wavelength (meters)

c = velocity of light in free space = 3×10^8 meters/second

f = frequency in hertz (cycles/second)

(6) If conductors are connected in a mesh or grid to form a multitude of low-impedance loops in parallel, there will be little voltage difference between any two points in the grid at all frequencies from 60 hertz up to a frequency where the length of one side of one square represents about 1/10 wavelength. A grid made up of 2 foot squares will at any point provide an effective equipotential ground reference point for signals up to more than 30 MHz. If such a grid is installed in the computer room and the enclosure or frame of each piece of data-processing equipment is connected to it by a short conductor, there should be no computer noise problems resulting from differences in ground potential between the frames of any two pieces of equipment.

(7) A raised floor in the computer room can be used as the reference grid if of the proper type and design. Most raised floors consist of vertical stanchions or corner supports 2 feet apart that hold up the 2-foot square floor tiles. If the floor is the type that has stringers between the stanchions and the stringers are positively mechanically bolted to them to make a good electrical connection, the stringers will form an excellent 2-foot square mesh. If the floor tiles or panels are metal-clad, they will further reduce the impedance between loops. This is probably the best and least-costly way to obtain the high-frequency reference ground grid. Floor tiles should be used that do not have a zinc electroplated-passivation coating on the tile's sheet metal pan, thereby avoiding potential problems with zinc whiskers. Computer room floor tile manufacturers have identified this problem, and no zinc electroplated floor tiles have been manufactured for several years.

(8) The frames of the data-processing equipment should be connected to the grid by the shortest possible leads with braided copper the preferred material, followed by copper strap, with round conductor least desirable, because braid provides the most effective and round conductor the least-effective results with high-frequency signals. Connections from the equipment frames to the raised-floor grid can easily be kept to 8 inches.

(9) If the bolted-stringer type of floor is not installed, a grid can be created by laying a mesh on the true floor, under the raised floor. This mesh also can be of copper wire, (least desirable) flat copper strap, or braided copper strap (most desirable), electrically connected every 2 feet to make a grid of 2-foot squares. Since this grid is on the true floor, it is about 2 feet farther from the equipment enclosures and requires a longer connecting strap from enclosure to grid, reducing its effectiveness a little.

(10) Additional protection against false signals is obtained by using shielded cables to interconnect equipment or using filters and traps to keep unwanted signals out of the system. If shielded cables are used, only one end of the shielding may be grounded. Grounding both ends of

the shield would provide a closed current loop that could create an induced current in the shield and damage the shield through overheating.

(11) A higher frequency network reference signal subsystem may be required for frequencies of concern higher than 30 MHz. The optimum interconnecting cable and/or mesh spacing of the equipotential plane should be one-tenth to one-twentieth of the wavelength of concern. For a 500 MHz signal, one-tenth of a wavelength is about 1.2 inches. This small mesh spacing may not be feasible; therefore, the mesh spacing should be as small as practical. As a design objective, the mesh grid openings should be no larger than 4 inches. A ground reference plane made up of a copper mesh with four-inch openings may be embedded in the concrete floor of new facilities. Another option for existing or new facilities is to install a metal sheet or roll of aluminum, copper, or phosphor bronze under floor tiles or carpet. When it is impractical to install an equipotential plane under the floor surrounding the ADP equipment, thin metal sheets can be installed in or on the ceiling of the equipment room. Additional details can be found in MIL-HDBK-419A, Section 1.5.1, Higher Frequency Network.